Host preference of the plum curculio

Tracy C. Leskey* & Starker E. Wright

USDA-ARS, Appalachian Fruit Research Station, 2217 Wiltshire Road, Kearneysville, WV 25430-2771, USA

Abstract

We assessed host preference of adult plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), based on the total number of mark-released and wild adults recovered and the total distance moved by mark-released adults in an orchard whose layout was designed to specifically allow foraging plum curculios to choose among host tree species. Host trees included apple, *Malus domestica* Borkh.; pear, *Pyrus communis* (L.); peach, *Prunus persica* (L.) Batsch; apricot, *Prunus armeniaca* L.; tart cherry, *Prunus cerasus* L.; sweet cherry, *Prunus avium* (L.); European plum, *Prunus domestica* L.; and Japanese plum, *Prunus salicina* Lindl. (all Rosaceae). We released 2900 marked adults and recovered 17.7%. We used screen traps to provide a measure of the number of adults that arrived at and climbed up particular host trees and found that significantly greater numbers of marked adults and the greatest number of wild adults were recovered from screen traps attached to Japanese plum. We sampled host tree canopies by tapping limbs to provide a measure of the number of adults within a tree canopy at a particular moment. Again, significantly greater numbers of marked and wild adults were recovered from plum species, with no difference between Japanese and European plum cultivars for marked individuals, but with significantly greater numbers of wild individuals recovered from Japanese plum. The preference index (PI) for Japanese plum based on total distances moved by all marked adults recovered on Japanese plum divided by the total distance moved by marked adults recovered on other host trees indicated that Japanese plum was the most highly preferred host, followed by European plum, peach, sweet cherry, tart cherry, apricot, apple, and pear, respectively.

Introduction

The plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), is a serious pest of stone and pome fruit in eastern North America (Racette et al., 1992; Vincent et al., 1999). In the spring, adults move from overwintering sites toward orchards where they likely meet and mate in or near host fruit trees (Smith & Salkeld, 1964; Racette et al., 1992; Piñero et al., 2001). Adults feed on fruit buds and developing fruit, and females also oviposit in developing fruit soon after petal fall (LaFleur & Hill, 1987; Chouinard et al., 1993), cutting a small, crescent-shaped flap in the fruit skin and then depositing an egg (Quaintance & Jenne, 1912; Chapman, 1938). Subsequent larval feeding can lead to either fruit drop (Levine & Hall, 1977) or severe scarring (Quaintance & Jenne, 1912; Racette et al., 1992).

There has been a great deal of effort directed toward development of trap-based (Piñero et al., 2001; Johnson

et al., 2002; Leskey & Prokopy, 2002; Prokopy et al., 2003; Leskey & Wright, 2004a) and trap tree-based (Prokopy et al., 2003, 2004) monitoring systems for plum curculio in commercial orchards. Both approaches rely heavily on olfactory cues to serve as attractants. Currently, these attractants include grandisoic acid, a male-produced aggregation pheromone (Eller & Bartelt, 1996), as well as fruit-based compounds (Leskey et al., 2001; Piñero et al., 2001; Prokopy et al., 2001). One fruit-based compound in particular, benzaldehyde, synergizes plum curculio responses to grandisoic acid (Piñero & Prokopy, 2003). Although synergism between benzaldehyde and grandisoic acid results in increased adult captures, captures in baited traps declined rapidly after fruit set (Prokopy et al., 2003; Leskey & Wright, 2004a) indicating that volatiles released by rapidly developing fruit could be outcompeting synthetic attractants. Indeed, Leskey & Wright (2004b) found that the presence of host apple trees did have a significant impact on plum curculio responses to baited traps, indicating that olfactory cues produced by host trees,

*Correspondence: E-mail: tracy.leskey@ars.uda.gov

particularly after fruit set, are more attractive to plum curculios than synthetic attractants.

One approach taken toward identification of more competitive host plant-based includes identification of attractants based not just on fruit odor, but on foliar and woody tissues as well, because plum curculios move from overwintering sites to locate host trees prior to fruit being available (Lafleur & Hill, 1987; Piñero et al., 2001; Leskey & Wright, 2004a). However, even traps baited with attractive blends of volatiles released by foliar and woody tissues of the European plum cultivar 'Stanley', in combination with benzaldehyde and grandisoic acid, failed to reliably attract plum curculios toward traps deployed in apple orchards after fruit set (TC Leskey, unpubl.).

Plum curculio has a relatively broad host range, feeding on plants belonging to six genera in the family Rosaceae (Maier, 1990), a single genus in the family Ericaceae (Beckwith, 1943; Mampe & Neunzig, 1967; Jenkins et al., 2006), and a single genus in the family Vitaceae (Jenkins et al., 2006) and therefore would be considered to be an oligophagous herbivore based on this host use pattern (Bernays & Chapman, 1994). Cultivated hosts in the family Rosaceae based on the studies of Maier (1990) include apple, *Malus domestica* Borkh.; peach, *Prunus persica* (L.) Batsch; sweet cherry, *Prunus avium* (L.); tart cherry, *Prunus cerasus* L.; Japanese plum, *Prunus salicina* Lindl.; European plum, *Prunus domestica* L.; quince, *Cydonia oblonga* Miller; and pear, *Pyrus communis* (L.). Other cultivated rosaceous hosts include nectarine *Prunus persica* (L.) Batsch var. Nectarina (Howitt, 1993) and apricot, *Prunus armeniaca* L. (Howitt, 1993; Brown, 2005). In the family Ericaceae, highbush blueberry, *Vaccinium corymbosum* L. (Beckwith, 1943; Mampe & Neunzig, 1967; Polavarapu et al., 2004) and deerberry, *Vaccinium stamineum* L. are considered to be hosts. In the family Vitaceae, plum curculio larvae were found to be developing successfully in muscadine, *Vitis rotundifolia* Michaux (Jenkins et al., 2006).

Interestingly, identification of plant volatile-based attractants for plum curculio have relied on only two of these hosts, apple, *M. domestica*, and the European plum, *P. domestica* varieties 'Stanley' and 'Fellenburg' (Leskey et al., 2001; Piñero et al., 2001; Prokopy et al., 2001; Leskey et al., 2005). Presumably, the most highly preferred host of plum curculio should yield the most promising source material for identification of competitive host plant-based attractants. Quaintance & Jenne (1912) stated that plum curculio prefer in decreasing relative order: plum, cherry, apricot, apple, pear, and quince. Chandler (1932) and Armstrong (1958) stated that peach is more preferred than apple. However, conclusions from these studies were drawn from indirect information, that is, oviposition scars present on fruit on a particular sample date, and not on total numbers of adults present on a particular host throughout the season. Preference is defined as selection of an item from a choice of items (Bernays & Chapman, 1994), and there never has been a study reported that has directly addressed the question of host preference of plum curculio based on adults being given a true choice. Therefore, we conducted an extensive mark–release–recapture experiment and complimentary study of wild populations, both under natural conditions in a mixed fruit orchard, to determine if plum curculio has a preferred cultivated host plant.
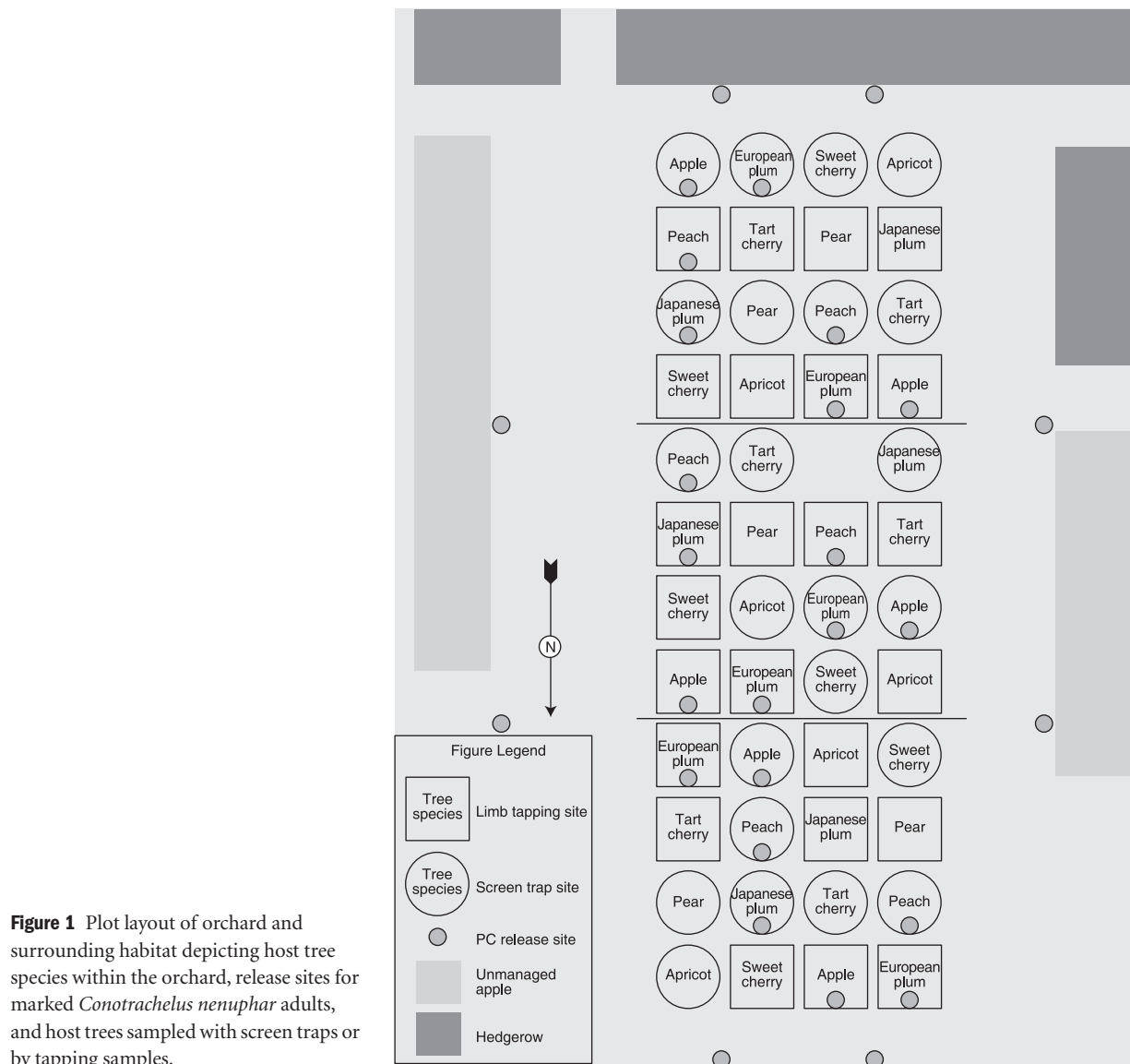
Materials and methods

Experimental orchard set-up

The mixed fruit orchard used in this study was planted in 1997 at the Appalachian Fruit Research Station (Kearneysville, WV, USA). The orchard was planted in a 4×4 partial Latin square replicated three times. Eight species of fruit trees were planted in each square and replicated twice. They included apple, *M. domestica*, cultivars 'Granny Smith' and 'Empire'; pear, *P. communis* cultivars 'Beurre Bosc' and 'Seckel'; peach, *P. persica* cultivar 'Loring'; apricot, *P. armeniaca* cultivar 'Deatrick'; tart cherry, *P. cerasus* cultivar 'Montmorency'; sweet cherry, *P. avium* cultivars 'Ulster' and 'Emperor Francis'; European plum, *P. domestica* cultivar 'Stanley'; and Japanese plum, *P. salicina* cultivars 'Santa Rosa' and 'Formosa'. The orchard consisted of four rows of 12 trees, planted with 6 m between rows and 6 m between trees. Surrounding the orchard were two unmanaged apple orchards (~30 m to the east and ~20 m to the west), a hedgerow (~20 m to the south), and an open field to the north (Figure 1). Throughout the study, the orchard received no insecticide applications and one fungicide application of fenbucanazole on 17 May to control brown rot.

Emergence traps based on the specifications of Piñero et al. (2005) were deployed within and adjacent to the experimental orchard to monitor timing and duration of emergence of the wild population of plum curculio. Seven traps were placed within each replicate, with a single trap positioned beneath the outer edge of the dripline (1 m from the trunk) of the canopy of two apples, two peaches, and two European plums and a single Japanese plum. Six emergence traps were deployed in the hedgerow and two emergence traps were deployed in the open field. These sites were chosen as locations for monitoring emergence of overwintering adults because adults are known to overwinter outside the orchard in areas with thick layers of fallen leaves, grass, and/or duff (Smith & Flessel, 1968; LaFleur et al., 1987) and within the orchard (Piñero et al., 2005), most likely near highly utilized host trees (Brown, 2005).

Screen traps consisting of folded vinyl screen sized to encircle the tree trunk (New York Wire Co., Mt. Wolf, PA,

Figure 1 Plot layout of orchard and surrounding habitat depicting host tree species within the orchard, release sites for marked *Conotrachelus nenuphar* adults, and host trees sampled with screen traps or by tapping samples.

USA) and attached at the base of tree trunks as described by Mulder et al. (1997) and modified according to the specifications of Leskey & Wright (2004a) were deployed within each replicate, one on each host tree type including apple, peach, apricot, tart cherry, sweet cherry, European plum, and Japanese plum. Screen traps were deployed on pear trees in replicates 1 and 3 only because a pear tree had been lost in replicate two. All remaining trees within each replicate were not subject to a trap directly attached to the tree itself (Figure 1).

Plum curculios

Plum curculios used as release subjects in this experiment were from a laboratory colony established in 2001 and augmented annually with wild individuals. Adults were reared in the laboratory at 25 °C and L14:D10 on a diet of green thinning apples based on the methods of Amis & Snow (1985). Directly after emergence, adults were held in groups of 100 in an environmental chamber for 1–5 months depending on emergence date (28 October 2003 to 3 March 2004) with over 90% of adults being held for a minimum of 2 months. Adults were held in 4 l plastic jars filled with ~10 cm of a moistened 50:50 soil:vermiculite mixture, and provided with apple foliage, and paper towels as sources of cover. The regime used in the chamber was meant to simulate ambient overwintering conditions experienced by wild adults. Initially, the chamber was set at 5 °C and L10:D14 in late November 2003. Daylength was

decreased and then increased at weekly increments until late March 2004 based on natural daylengths experienced in nature. Temperature was increased by 5 °C at weekly intervals beginning in early March. When adults showed signs of becoming active (movement observed in over-wintering jars), they were removed from the chamber and sexed according to the methods of Thomson (1932). Adults then were returned to the chamber in single sex groups of approximately 40 individuals held in wax-coated cups (473 ml) with clear plastic lids with a source of water (wetted cotton dental wick), but no food.

From 24 March to 7 April 2004, sexed adults were painted with one small dot Testors enamel paint (Testors Corp., Rockford, IL, USA) on their right and left elytra coded for sex and release site. This paint is durable and has no detectable effects on survivorship or behavior (TC Leskey, pers. obs.). Twenty-nine groups of 50 males and 50 females were marked for subsequent release. Adults were not given food during this period, but were only given access to water and held at 20 °C and L14:D10 to simulate conditions experienced by adults in nature. On 8 April 2004, groups of 50 males and 50 females were released at 21 different locations within the orchard and eight outside the orchard, each corresponding with the location of an emergence trap (Figure 1). As previously described for emergence traps, these release sites were chosen based on the likelihood that wild populations would overwinter at these locations (Figure 1). Within the orchard, adults were released 2 m away from the trunk and beyond the canopy dripline of the nearest host tree. Release date was based on first capture of wild adults in emergence traps deployed within and outside the experimental orchard (TC Leskey, unpubl.).

Sampling methods

Beginning on 6 April 2004, each screen trap was sampled for the presence of plum curculios. All adults were removed from traps, placed in individual vials, and taken to the laboratory. Traps were checked twice weekly through 28 July and weekly thereafter until 30 September. A final sample was conducted on 28 October. Beginning on 16 April (based on captures in screen traps indicating adults were moving into host fruit trees), the remaining trees without screen traps in each replicate were sampled by using a beating stick to tap branches in the canopy. A large circular collection sheet (3.36 m in diameter) was positioned directly beneath the tree canopy to capture falling adults. This sampling regime involved moving around the entire tree and tapping all large limbs (>10 cm in diameter). Sampled trees included one apple, pear, peach, apricot, tart cherry, sweet cherry, European plum, and Japanese plum per replicate (Figure 1). Sampling was conducted between 16:00 and 19:00 hours during the same sampling dates as those for screen traps. All adults recovered from the sheet were placed in individual vials and taken to the laboratory.

Statistics

Data were analyzed using the general linear model procedure (SAS Institute, 2001) to construct analysis of variance (ANOVA) tables for mean distance moved by marked adults based on the distance from release habitats to specific host tree recovery locations, and the number of marked and wild adults captured in screen traps and recovered from tapping samples from various host trees over the entire sampling period. Dependent variable data were $\log(y + 1)$ transformed if homogeneity-of-variance assumptions were violated according to Bartlett's Test for Homogeneity (SAS Institute, 2001). Each model evaluated the effect of the following class variables, host tree species and sex. If the effect of sex was not significant, it was dropped from the model. When the general linear model indicated significant differences, multiple comparisons were calculated using the Student-Newman-Keuls multiple range test. Although release sites for marked adults were located 2 m from apple, European plum, Japanese plum, and peach trees (based on location of emergence traps) and 4 m to the closest adjacent host tree (Figure 1) we analyzed data associated with recaptured adults from all host trees equally based on the following criteria: (i) sites were chosen based on likelihood of wild populations being present; (ii) releases were conducted before any foliar or fruiting tissues were available; (iii) of those recaptured, less than 27% was recovered from the host tree nearest to their release habitat; and (iv) relative numbers of marked and wild adults recovered from particular host trees were similar. A preference index (PI) was developed for Japanese plum cultivars relative to other host trees. The PI was calculated by dividing the total distance moved by all marked adults recovered on Japanese plum by the total distance moved by marked adults recovered on other host trees (based on the six recovery locations for each host). Thus, the greater the PI, the more highly preferred Japanese plum was relative to other host trees. Because there were only five recovery locations for pear, a correction was applied to total distance moved; the average distance traveled per recovery location (based on the five available recovery locations) was multiplied by 6 to calculate total distance moved.

Results

Capture profiles

We captured 310 marked and 1035 wild individuals in screen traps and 202 marked and 856 wild individuals in

Figure 2 Season long captures of marked-recovered and wild *Conotrachelus nenuphar* adults from screen traps and tapping samples relative to the phenology of Japanese plum.
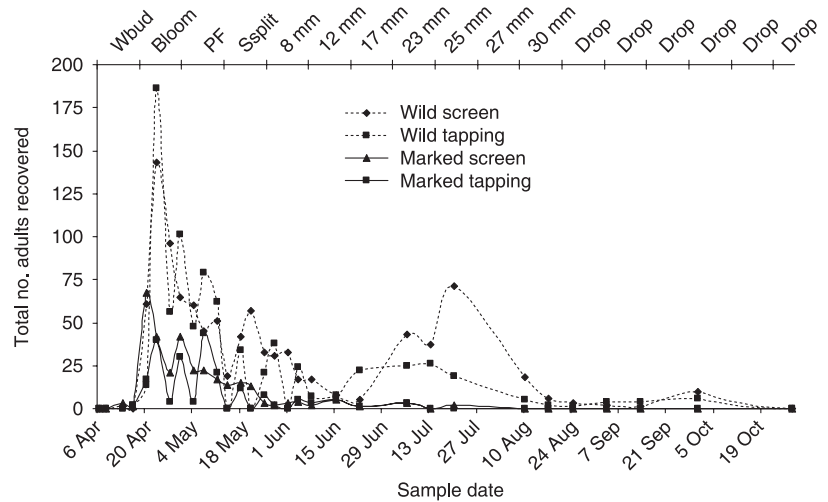
tapping samples. Based on the phenology of Japanese plum, between white bud and bloom (6–13 April), we captured four adults (one wild and three marked in screen traps). From petal fall to shuck split (14–27 April), we captured 742 adults (300 wild and 119 marked individuals in screen traps and 258 wild and 65 marked individuals in tapping samples). After shuck split until fruit reached 30 mm (28 April–28June), we captured 1305 adults (513 wild and 164 marked individuals in screen traps and 492 wild and 136 marked individuals in tapping samples) and after fruit had dropped to the ground (29 June–28 October), we captured 333 adults (221 wild and three marked individuals in screen traps and 106 wild and three marked individuals in tapping samples) (Figure 2). We recovered 17.7% of marked adults indicating that the size of the wild population within the experimental area was ~10, 171 based on the Lincoln index (Lincoln, 1930).

Marked adults

Among marked adults, the effect of sex was not significant and it was dropped from the model. There were significant differences in distances moved from each release habitat ($F_{5,506} = 42.37$, P<0.0001) based on the distance between release site to recovery location. Adults released outside the orchard in hedgerows moved significantly further than those released in the field and further than those released near apple, peach, European plum, or Japanese plums trees within the orchard (Table 1). Among all recovery sites within the orchard, there were significant differences in distances moved to host trees based on tapping samples ($F_{8,193} = 5.22$, P<0.0001). The effect of sex was significant (P = 0.0249) with adult females (13.41 m ± 1.24 SE) moving significantly further than adult males (10.68 m ± 1.07 SE). The effect of host tree also was significant

(P<0.0001); more adults moved significantly further (based on the distance between each release site and recovery location) to reach Japanese plum compared to apple based on tapping samples. There were significant differences in distances moved to host trees based on screen trap captures ($F_{7,302} = 3.53$, P = 0.0012); the effect of sex was not significant and was dropped from the model. More adults moved significantly further to reach pear and sweet cherry compared to apple based on screen trap samples (although only three adults were recovered from screen traps attached to pear). For both screen traps and tapping samples, the highest percentage of marked individuals was recovered from Japanese and European plum (Table 2).

For screen traps, the model was significant (the effect of sex was not significant and was removed from the model); there were significant differences in captures of adults in

Table 1 For each release habitat, total number of marked *Conotrachelus nenuphar* adults released, total number (percentage) recovered, and mean distance traveled by captured adults based on the distance from release habitat to recovery location from 6 April to 28 October, 2004

Release habitat	Total no. released	Total (%) recovered	Mean distance (± SE)[1]
Apple	600	115 (19.2%)	11.91 ± 1.06c
European plum	600	126 (21.0%)	8.25 ± 0.86c
Japanese plum	300	69 (23.0%)	8.14 ± 1.60c
Hedge	600	37 (6.2%)	35.71 ± 3.27a
Field	200	26 (13.0%)	24.22 ± 3.19b
Peach	600	139 (23.2%)	9.29 ± 0.68c

[1]Means in the same column followed by a different letter are significantly different according to Student-Newman-Keuls multiple range test (P<0.05).

Recovery host	Screen traps			
	Nearest host tree[1]	Host trees >2 m[2]	All host trees (%)	Mean distance (± SE)[3]
Apple	13	8	21 (6.8%)	7.72 ± 2.72b
Apricot	–	16	16 (5.2%)	12.76 ± 1.54ab
European plum	27	42	69 (22.3%)	12.30 ± 2.20ab
Japanese plum	35	81	116 (37.4%)	11.97 ± 1.18ab
Peach	17	20	37 (37.0%)	14.38 ± 3.25ab
Pear	–	3	3 (3.0%)	16.23 ± 3.21a
Sweet cherry	–	24	24 (7.7%)	17.45 ± 2.28a
Tart cherry	–	24	24 (7.7%)	11.52 ± 2.76ab

Recovery host	Tapping samples			
	Nearest host tree[1]	Host trees >2 m	Total (%)	Mean distance (± SE)[3]
Apple	7	6	13 (6.4%)	4.57 ± 0.87b
Apricot	–	12	12 (5.9%)	13.02 ± 3.59ab
European plum	32	39	71 (35.2%)	11.04 ± 1.60ab
Japanese plum	3	63	66 (32.7%)	15.53 ± 1.49a
Peach	3	5	8 (4.0%)	9.66 ± 2.96ab
Pear	–	3	3 (1.5%)	6.36 ± 0.13ab
Sweet cherry	–	12	12 (5.9%)	7.62 ± 0.71ab
Tart cherry	–	17	17 (8.4%)	11.95 ± 1.46ab

Table 2 Total number of marked *Conotrachelus nenuphar* adults recovered from the host tree nearest to their release habitat, from host trees >2 m from their release habitat, and from all host trees combined, with the percentage recovered from each host in parentheses, and the mean distance moved based on release site and recovery point to reach each screen trap or tapped tree recovery host from 6 April to 28 October 2004
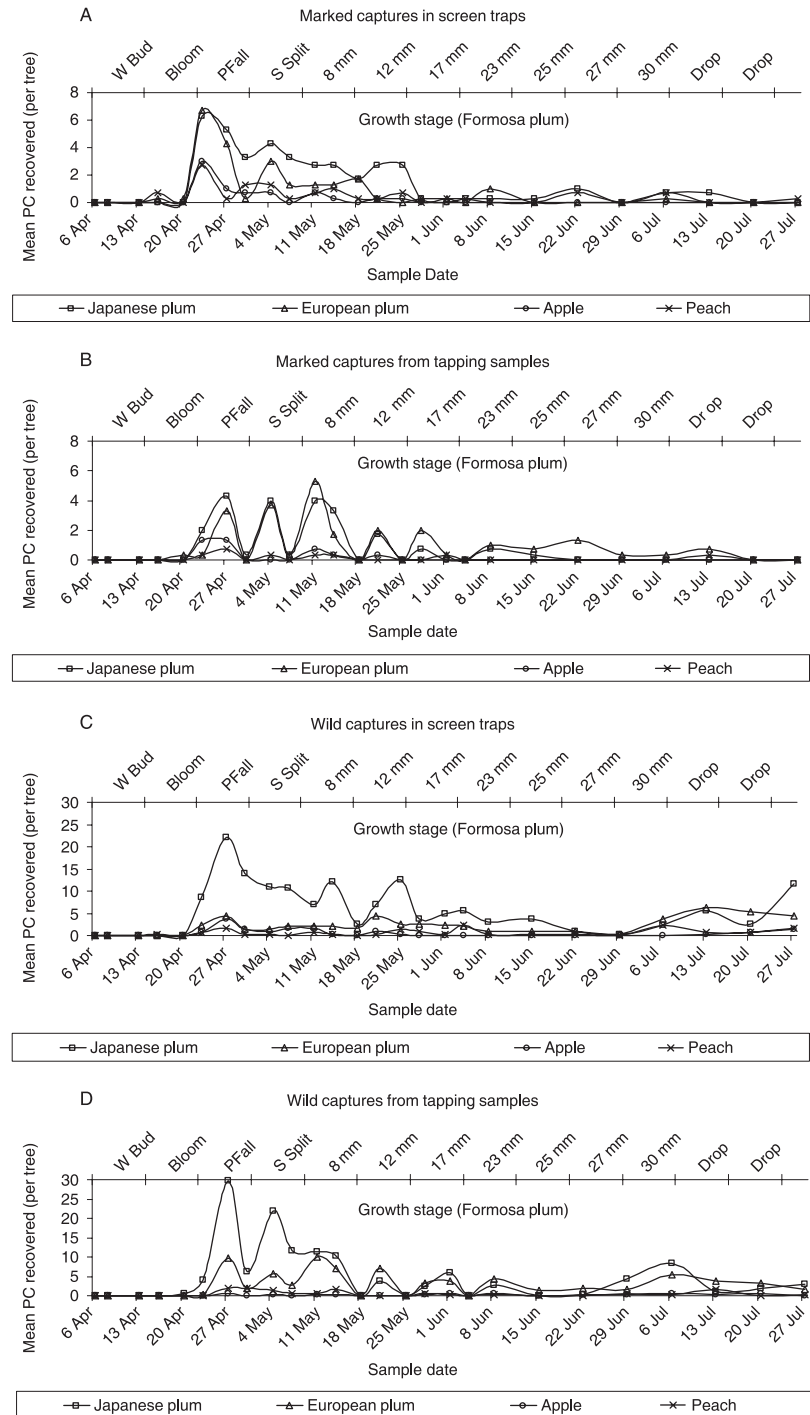
[1]Total number recovered from the host tree nearest to release habitat (based on release sites 2 m from apple, European plum, Japanese plum, and peach trees).
[2]Total number recovered from all other host trees >2 m from release habitat.
[3]Means in the same column followed by a different letter are significantly different according to Student-Newman-Keuls multiple range test (P<0.05).

screen traps attached to various host trees ($F_{6,14}$ = 33.33, P<0.0001). Significantly more adults were captured in screen traps attached to Japanese plum trees compared to any other host (Table 3). Based on the phenology of Japanese plum, the mean number of adults recovered from screen traps per tree from petal fall onward was generally higher on Japanese plum than on European plum, peach, or apple, even after fruit had dropped from the trees (Figure 3A).

There were significant differences in numbers of adults recovered from tapping samples from different host trees as well ($F_{7,16}$ = 8.77, P = 0.0002). Again, the effect of sex

Table 3 Mean (± SE) number of marked and wild *Conotrachelus nenuphar* adults captured in screen traps (n = 3) attached to and recovered from tapping samples (n = 3) of various host trees from 6 April to 28 October 2004

Host tree	Screen traps		Host tree	Tapping samples	
	Marked[1]	Wild		Marked	Wild
Apple	7.00 ± 1.00c	17.00 ± 1.52b	Apple	4.33 ± 0.88bc	6.67 ± 4.18b
Apricot	5.33 ± 0.88c	40.00 ± 13.45b	Apricot	4.00 ± 1.52b	22.33 ± 4.84b
European plum	23.00 ± 2.31b	57.67 ± 9.77ab	European plum	23.67 ± 6.23a	77.33 ± 24.74b
Japanese plum	38.67 ± 2.73a	157.67 ± 82.01a	Japanese plum	22.00 ± 5.29a	132.00 ± 41.14a
Peach	12.33 ± 0.88c	19.33 ± 2.60b	Peach	2.67 ± 0.88b	13.67 ± 5.36b
Sweet cherry	8.00 ± 2.52c	28.00 ± 8.62b	Pear	1.00 ± 0.58b	7.67 ± 5.24b
Tart cherry	8.00 ± 3.06c	23.00 ± 1.00b	European plum		
			Sweet cherry	4.00 ± 1.00b	7.67 ± 3.71b
			Tart cherry	5.67 ± 1.45b	18.00 ± 5.13b

[1]Means in the same column followed by a different letter are significantly different according to Student-Newman-Keuls multiple range test (P<0.05).

Figure 3 Season long captures of mark-recovered and wild plum curculio (PC), *Conotrachelus nenuphar*, adults from screen traps on or from tapping samples from Japanese plum, European plum, peach, and apple based on the phenology of Japanese plum.

was not significant and was removed from the model. Significantly more adults were recovered from European and Japanese plum trees than from any other host (Table 3). Based on the phenology of Japanese plum, the mean number of adults recovered from tapping samples from petal fall until fruit reached ~10 mm fruit was generally higher on Japanese plum than on European plum, peach, or apple (Figure 3B).

The preference index for Japanese plum relative to other host trees indicated that Japanese plum cultivars were 1.5

Table 4 Total distance traveled by all marked-recovered *Conotrachelus nenuphar* adults to six recovery locations, and PI for Japanese plum from 6 April to 28 October 2004

Host	Total distance traveled	Japanese plum PI[1]
Apple	207.8	11.5
Apricot	360.3	6.7
European plum	1590.2	1.5
Japanese plum	2398.0	–
Peach	598.4	4.0
Pear[2]	81.4	29.7
Sweet cherry	510.3	4.7
Tart cherry	479.7	5.0

[1]Preference index = Total distance traveled (m) to Japanese plum/ Total distance traveled to other host.
[2]True total distance traveled was 67.8 m (based on five recovery locations), but a correction was applied to 'Total distance traveled' (based on the average distance traveled per recovery site × 6).

times more preferred than the European plum cultivar 'Stanley', 4.0–6.7 times more preferred than peach, sweet cherry, tart cherry, and apricot, 11.5 times more preferred than apple, and 29.7 times more highly preferred than pear (Table 4).

Wild adults

Among wild populations, the model was significant and there were significant differences in captures of adults in screen traps attached to various host trees ($F_{6,14}$ = 5.97, P = 0.0028); the effect of sex was not significant and removed from the model. Significantly more adults were captured in screen traps attached to Japanese plum trees compared to any other host, with the exception of European plum (Table 3). Based on the phenology of Japanese plum, the mean number of adults recovered from screen traps per tree from petal fall until fruit reached ~10 mm was generally higher on Japanese plum than on European plum, peach, or apple (Figure 3C).

There were significant differences in number of adults recovered from tapping samples of different host trees ($F_{7,16}$ = 6.47, P = 0.0008). The effect of sex was not significant and was removed from the model. Significantly more adults were recovered from Japanese plum trees than from any other host with the number of recovered adults being 1.5 times greater than those recovered from European plum (Table 3). Based on the phenology of Japanese plum, the mean number of adults recovered from tapping samples from petal fall onward was generally higher on Japanese plum and European plum than on peach or apple (Figure 3D).

Discussion

All phytophagous insects exhibit some level of selectivity of plants they will consume. Preferred host plants are considered to be those species consumed to a greater degree than other species within the context of a local environment and population (Hassell & Southwood, 1978). Preference by definition is based on selection of an item from a choice of items (Bernays & Chapman, 1994). Or as Miller & Strickler (1984) explained, cases of preference or selection 'apply when multiple items come into an insect's sensory field simultaneously and a given item is consistently taken'. The host preference of plum curculio, an oligophagous herbivore, has never been rigorously identified based on these criteria.

Some studies have relied on an indirect measurement [oviposition scars present on fruit (Quaintance & Jenne, 1912; Yonce et al., 1995)], with little detail as to the location of samples [i.e., within one orchard location or across multiple locations (Quaintance & Jenne, 1912)], or from samples taken from a standard modern orchard block with entire rows are comprised of a single host tree (Yonce et al., 1995). In general, the distribution of plum curculio damage (oviposition scars) under field conditions tends to be aggregated in trees of the border row or peripheral zone compared to trees within the interior of orchards (Quaintance & Jenne, 1912; Chapman, 1938; Le Blanc et al., 1984) because in managed orchards in particular, adults immigrate from outside the orchard and therefore encounter border rows first. Uniformly distributed populations of adults were not likely to be present among various locations of host trees used for these assessments, and as required by the definition of preference, adults were not allowed to choose an item from a choice of items due to the spatial arrangement of hosts.

Therefore, we used a more direct method to assess preference of plum curculio, namely, the total number of adults recovered from host fruit trees in an orchard whose spatial arrangement allowed foraging plum curculios to choose among host tree species and that had a large wild population that overwintered within the orchard itself. We assessed adult choice based on two methods. First, we used screen traps that provide a measure of the number of adults that arrived at and climbed up particular host trees. These traps sampled the population continuously and likely measured preference based on host-finding behavior [i.e., the ability to detect and locate a particular host from a distance (Miller & Strickler, 1984; Bernays & Chapman, 1994)]. We found that significantly greater numbers of marked adults and the greatest number of wild adults were recovered from screen traps attached to Japanese plum compared to any other host (Table 3). Our other sampling method

involved tapping limbs in the canopy of host trees in the late afternoon to early evening hours as this is when adults tend to be present in host trees in greater numbers, particularly after bloom (Chouinard et al., 1992). This technique provided a measure of the number of adults within a host tree canopy at a particular moment and indicated preference based on host-finding and/or acceptance [i.e., confirming the appropriateness of the plant after arrival (Bernays & Chapman, 1994)]. In this case, adults had located and arrived within host tree canopies, but because this estimate was based on adults present in the tree at a particular moment, we do not know how long they had been there. However, results of these samples revealed a very similar pattern to that of screen trap samples. Significantly greater numbers of marked and wild adults were recovered from plum species, with no difference between Japanese and European plum cultivars for marked individuals, but with significantly greater numbers of wild individuals recovered from Japanese plum compared with any other host (Table 3). The preference index (PI) for Japanese plum based on total distances moved by all mark-recovered adults regardless of sampling regime indicated that Japanese plum was the most highly preferred host (Table 4). Thus, plum curculio adults appear to move in greater numbers and over greater distances (based on distance from release habitat to recovery site) to reach preferred hosts, in this case Japanese plum.

The ancestral host of plum curculio is considered to be native species of plum found in North America (Quaintance & Jenne, 1912; Chapman, 1938), including *P. americana* (Quaintance & Jenne, 1912; Maier, 1990), *P. hortulana* Bailey (Quaintance & Jenne, 1912), *P. angustifolia* (Quaintance & Jenne, 1912; Jenkins et al., 2006), *P. maritima* Marsh (Maier, 1990), and *P. umbellata* Elliot (Jenkins et al., 2006). However, it also readily infests cultivated Japanese and European plum cultivars (Quaintance & Jenne, 1912; Maier, 1990; Brown, 2005), with what appears to be a preference for Japanese plum based on our studies. Interestingly, Japanese plum cultivars could have native North American plum species, the native host of plum curculio, as part of their parentage (Jones, 1928) while European plum varieties do not (Zohary, 1992). Many Japanese plum cultivars developed in the USA were generated by Luther Burbank who crossed imported Japanese plum, *P. salicina* Lindl with Eurasian *P. cerasifera*, Chinese *P. salicina*, *P. simonii* Carr, and native North American plum species such as *P. americana* (Byrne, 1989). The parentage of the cultivar 'Formosa' is assumed to be 50% *P. salicina* based on morphological traits (Howard, 1945). The parentage of the cultivar 'Santa Rosa' is unknown but believed to be 50% *P. salinica*, 25% *P. simonii*, and 25% *P. americana* (Howard, 1945), although recent analyses suggest that *P.*

americana may not be part of the genetic parentage (Boonprakob & Byrne, 2003). The hypothesis that Japanese plum cultivars may have native North American plum species as part of their parentage is intriguing and could explain preference for these cultivars compared with the European plum cultivar 'Stanley'. Quaintance & Jenne (1912) also observed that Japanese plum cultivars appeared to be more susceptible to plum curculio oviposition injury than European varieties.

Our results indicate that Japanese plum cultivars 'Formosa' and 'Santa Rosa' are more highly preferred than the European plum cultivar 'Stanley'. They are also more highly preferred than any other stone fruit or pome fruit host. Throughout the season, more adults were recovered from Japanese plum compared to apple or peach, even after plums had dropped from the trees (Figures 2 and 3). Japanese plum may provide extremely attractive source material for identification of competitive attractants for plum curculio for use in monitoring traps in apple and peach orchards, particularly based on our recovery results within our experimental plot. In general, greater numbers of adults were recovered from Japanese plum than from peach or apple trees throughout the season even after plums had dropped from trees (Figure 3). We plan to pursue the identification of attractive host plant volatiles from Japanese plum in the future to complement previous studies based on the European plum cultivars (Leskey et al., 2001; Leskey et al., 2005).

References

Amis A & Snow JJ (1985) *Conotrachelus nenuphar*. Handbook of Insect Rearing, Vol. 1 (ed. by P Singh & RF Moore), pp. 227–236. Elsevier Science Publishing, New York, NY, USA.

Armstrong T (1958) Life history and ecology of the plum curculio, *Conotrachelus nenuphar* (Hbst.) (Coleoptera: Curculionidae) in the Niagara peninsula, Ontario. Canadian Entomologist 90: 8–17.

Beckwith CS (1943) Insects Attacking Blueberry Fruit. New Jersey Agriculture Experiment Station Bulletin 684.

Bernays EA & Chapman RF (1994) Host-Plant Selection by Phytophagous Insects. Chapman & Hall, Inc., New York, NY, USA.

Boonprakob U & Byrne DH (2003) Species composition of Japanese plum founding clones as revealed by RAPD markers. Acta Horticulturae 622: 473–476.

Brown MW (2005) Host utilization and phenology of injury by plum curculio (Coleoptera: Curculionidae) in West Virginia. Journal of Entomological Science 40: 149–157.

Byrne DH (1989) Inbreeding, coancestry, and founding clones of Japanese-type plums of California and the southeastern United States. Journal of the American Society of Horticultural Science 114: 699–705.

Chandler SC (1932) A seven year study of the plum curculio in southern Illinois. Journal of Economic Entomology 25: 101–105.

Chapman PJ (1938) The plum curculio as an apple pest. New York State Agricultural Experiment Station Bulletin 684: 1–75.

Chouinard G, Hill SB & Vincent C (1993) Spring behavior of the plum curculio (Coleoptera: Curculionidae) within caged dwarf apple trees. Annals of the Entomological Society of America 86: 333–340.

Chouinard G, Vincent C, Hill SB & Panneton B (1992) Cyclic behavior of the plum curculio (Coleoptera: Curculionidae) within caged dwarf apple trees. Journal of Insect Behavior 5: 385–392.

Eller FJ & Bartelt RJ (1996) Grandisoic acid, a male-produced aggregation pheromone for the plum curculio, *Conotrachelus nenuphar*. Journal of Natural Products 59: 451–453.

Hassell MP & Southwood TRE (1978) Foraging strategies of insects. Annual Review of Ecology and Systematics 9: 75–98.

Howard WL (1945) Luther Burbank's Plant Contributions. California Agriculture Experiment Station Bulletin 691.

Howitt AH (1993) Common Tree Fruit Pests. Michigan State University, North Central Regional Extension Publication 63, East Lansing, MI, USA.

Jenkins D, Cottrell T, Horton D, Hodges A & Hodges G (2006) Hosts of plum curculio, *Conotrachelus nenuphar* (Coleoptera: Curculionidae), in Central Georgia. Environmental Entomology 35: 48–55.

Johnson DT, Mulder PG, McCraw D, Lewis BA & Jervis B et al. (2002) Trapping plum curculio *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae) in the southern United States. Environmental Entomology 31: 1259–1267.

Jones DF (1928) Burbank's results with plums. Journal of Heredity 19: 359–371.

LaFleur G & Hill SB (1987) Spring migration, within-orchard dispersal & apple-tree preference of plum curculio (Coleoptera: Curculionidae) in southern Quebec. Journal of Economic Entomology 80: 1173–1187.

LaFleur G, Hill SB & Vincent C (1987) Fall migration, hibernation site selection, and associated winter mortality of plum curculio (Coleoptera: Curculionidae) in a Quebec apple orchard. Journal of Economic Entomology 80: 1152–1172.

Le Blanc JP, Hill SB & Paradis RO (1984) Oviposition in scout apples by plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae) and its relationship to subsequent damage. Environmental Entomology 12: 286–291.

Leskey TC & Prokopy RJ (2002) Developing a branch-mimicking trap for adult plum curculios. Entomologia Experimentalis et Applicata 102: 253–259.

Leskey TC, Prokopy RJ, Wright SE, Phelan PL & Haynes LW (2001) Evaluation of individual components of plum odor as potential attractants for adult plum curculios. Journal of Chemical Ecology 27: 1–17.

Leskey TC & Wright SE (2004a) Monitoring plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae) populations in apple and peach orchards in the mid-Atlantic. Journal of Economic Entomology 97: 79–88.

Leskey TC & Wright SE (2004b) Influence of host tree proximity on adult plum curculio (Coleoptera: Curculionidae) responses to monitoring traps. Environmental Entomology 33: 389–396.

Leskey TC, Zhang A & Herzog M (2005) Non-fruiting host tree volatile blends: novel attractants for the plum curculio (Coleoptera: Curculionidae). Environmental Entomology 34: 785–793.

Levine E & Hall FR (1977) Effect of feeding and oviposition by the plum curculio on apple and plum abscission. Journal of Economic Entomology 76: 603–607.

Lincoln FC (1930) Calculating waterfowl abundance on the basis of banding returns. USDA Circular 118: 1–4.

Maier CT (1990) Native and exotic rosaceous hosts of apple, plum and quince curculio larvae (Coleoptera: Curculionidae) in the northeastern United States. Environmental Entomology 83: 1326–1332.

Mampe CD & Neunzig HH (1967) The biology, parasitism and population sampling of blueberry in North Carolina. Journal of Economic Entomology 60: 807–812.

Miller JR & Strickler KL (1984) Finding and accepting host plants. Chemical Ecology of Insects (ed. by WJ Bell & RT Cardé), pp. 129–157. Chapman & Hall, New York, NY, USA.

Mulder PG, McCraw BD, Reid W & Grantham RA (1997) Monitoring adult weevil populations in pecan and fruit trees in Oklahoma. Oklahoma State University, Extension Facts F-7190: 1–8.

Piñero JC, Jacome I, Cooley D & Prokopy RJ (2005) Penetration of plum curculio in commercial apple blocks of different tree size. Fruit Notes 70: 6–7.

Piñero JC & Prokopy RJ (2003) Field evaluation of plant odor and pheromonal combinations for attracting plum curculios. Journal of Chemical Ecology 12: 2735–2748.

Piñero JC, Wright S & Prokopy RJ (2001) Response of plum curculio (Coleoptera: Curculionidae) to odor-baited traps near woods. Journal of Economic Entomology 94: 1386–1397.

Polavarapu S, Kyryczenko-Roth V & Barry JD (2004) Phenology and infestation patterns of plum curculio (Coleoptera: Curculionidae) on four highbush blueberry cultivars. Journal of Economic Entomology 97: 1899–1905.

Prokopy RJ, Chandler BW, Dynok SA & Piñero J (2003) Odor-baited trees: a new approach to monitoring plum curculio (Coleoptera: Curculionidae). Journal of Economic Entomology 96: 826–834.

Prokopy RJ, Jacome I, Gray E, Trujillo G, Ricci M & Piñero J (2004) Using odor-baited trap trees as sentinels to monitor plum curculio (Coleoptera: Curculionidae) in apple orchards. Journal of Economic Entomology 97: 511–517.

Prokopy RJ, Phelan PL, Wright SE, Minalga AJ, Barger R & Leskey T (2001) Compounds from host odor attractive to plum curculio adults (Coleoptera: Curculionidae). Journal of Entomological Science 36: 122–134.

Quaintance AL & Jenne EL (1912) The plum curculio. USDA. Bureau of Entomology Bulletin 103, Washington DC, USA.

Racette G, Chouinard G, Vincent C & Hill SB (1992) Ecology and management of plum curculio in apple orchards. Phytoprotection 73: 85–100.

SAS Institute (2001) Version 8.2. SAS Institute Inc, Cary, NC, USA.

Smith EH & Flessel JK (1968) Hibernation of the plum curculio and its spring migration to host trees. Journal of Economic Entomology 61: 194–203.

Smith EH & Salkeld EH (1964) Ovary development and oviposition rates in the plum curculio, *Conotrachelus nenuphar* (Coleoptera: Curculionidae). Annals of the Entomological Society of America 57: 781–787.

Thomson RR (1932) Sex differentiation of adults of *Conotrachelus nenuphar*. Journal of Economic Entomology 25: 807–810.

Vincent C, Chouinard G & Hill SB (1999) Progress in plum curculio management: a review. Agriculture Ecosystems and the Environment 73: 167–175.

Yonce CE, Horton DL & Okie WR (1995) Spring migration, reproductive behavior, monitoring procedures and host preference of plum curculio (Coleoptera: Curculionidae) in *Prunus* species in Central Georgia. Journal of Entomological Science 30: 82–92.

Zohary D (1992) Is the European plum, *Prunus domestica* L., a *P. cerasifera* EHRH × *P. spinosa* L. allopolyploid? Euphytica 60: 75–77.